APPENDIX 14 Geology and Soils

Geology of the Project site and Surrounding Area

The coordinates of the target area 41°36'41.59" N 64°27'23.95" E

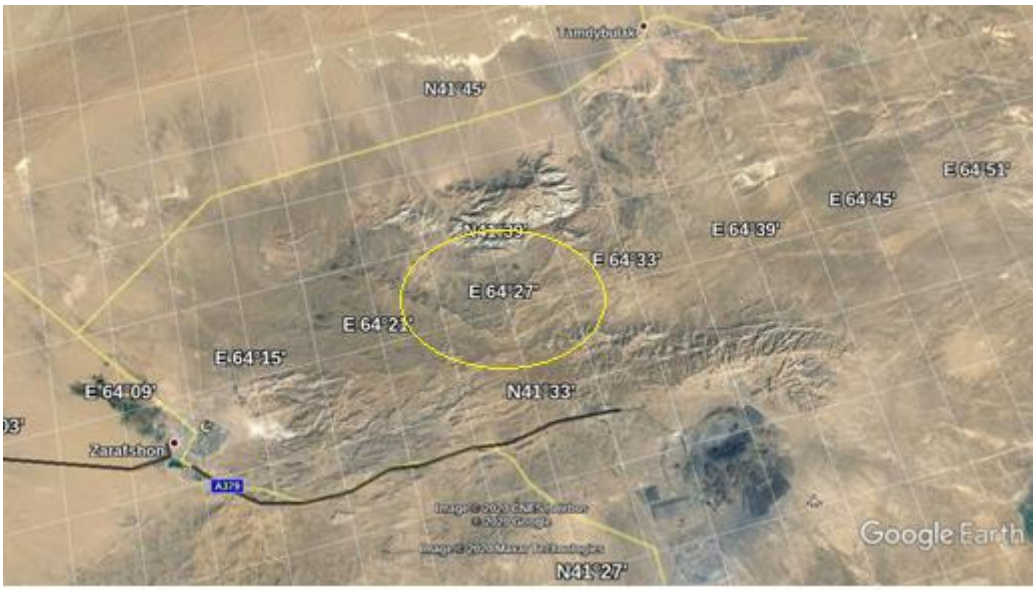

Figure 1. coordinates of the target area

The target area is formed by a relatively flat landscape with only a few moderate elevations (the highest 300m). The most important elevations are the Tamdytau (Tamdy-Mountains) about 30-40 km to the northwest of the deposit and the Aristantau (Aristan-Mountains) about 50 km to the south.

Most of the area is covered by platform sediments (gravel, sand and clay) of Mesozoic to Cenozoic ages. Topographic elevations and their surroundings form large tectonic windows within the sedimentary cover with outcrops of Caledonian to Hercynian fold and thrust rocks.

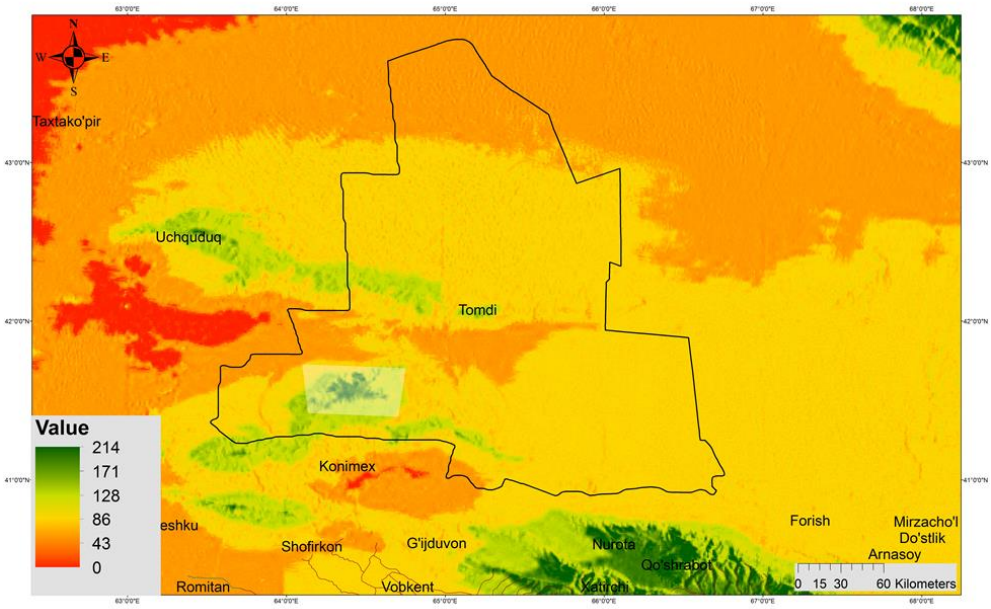

Figure 2. Digital elevation models (DEMs) from USGS series are arrays of elevation value for referenced area, the projection based on Universal Transverse Mercator (UTM) projection.

The area is a peculiar neotectonic uplift of the West-Northwest strike, composed of Paleozoic folded formations framed by a cover of Quaternary deposits.

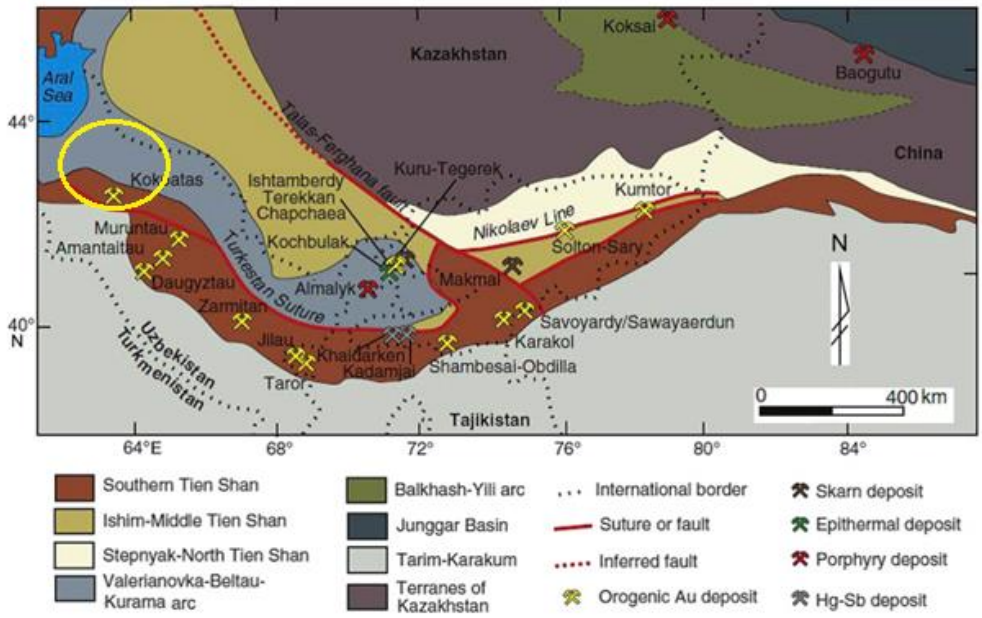

Figure 3. Configuration of geology in the Central Asia. Yellow circled area is targeted area where classified as southern tien shan and Valerianovka-Beltau-Kurama arc.

Credited: https://www.sciencedirect.com/science/article/pii/S1674987115001139

For the Kyzylkum profile, the Syrdarya Unit in the north is a cratonic Paleoproterozoic terrane, overlapped/stitched by a Paleozoic arc (this may explain the old ages reported by *Mirkamalov et al., 2012*[1], *Mirkamalov et al., 2012*[2]). Muruntau is located at the northern margin of the turbidite terrane that formed the accretionary complex between the Syrdarya and Alai Units. Nd–Hf model ages for studied samples from Kyzylkum (*Dolgopolova et al., 2013*) are shown in the juvenile signatures of youngest intrusions (with early Paleozoic model ages of protolith) discriminate nicely against the cratonic basement signatures of samples with middle to Neo–Proterozoic model ages (= recycled crust).

There is a fairly good agreement between the Hf and Nd model ages. The general linear relationship is what is expected if the two isotope systems reflect the same evolutionary processes. This matches interpretation of crust recycling and is in agreement with new results of U-Pb SHRIMP zircon dating of granitoid and metamorphic complexes including accretionary complexes of the Turkestan paleo-ocean and its northern and southern active continental margins (*Mirkamalov et al., 2012, Mirkamalov et al., 2012*). It was pointed out that the fold and fault belt of the Tien Shan system is extremely complex with various components that represent different orogenic events that span much of the Paleozoic and were later affected by an Alpine orogenic event (*Zonenshain et al., 1990*). *Drew with colleagues* (1996) highlighted that in the central to western Tien Shan, a 5–6 km wide structural zone strikes over 1,000 km north-westerly from the Fergana Valley in easternmost Uzbekistan, along the northern flank of the Nurata Mountains in the eastern Kyzylkum desert and thence northeast of the Tamdytau into the eastern Bukantau (*Akhber and Mushkin*, 1976). This structure is the suture zone that juxtaposes two continental masses, the Karakum massif to the southwest and the central Kazakhstan-North Tien Shan continent to the northeast (*Zonenshain et al., 1990*).

A characteristic feature of the suture zone are the W–NW-striking shear zones that splay off to the west from the main zone that subdivides the Kyzylkum desert region into a series of tectonic blocks. The main suture and the splays are offset by transverse northeast-striking shear zones (*Mushkin et al., 1975*). In the vicinity of Muruntau, two regional shear zones, the northwesterly striking Sangruntau-Tamdytau and the transverse Muruntau-Daugyztau, developed during the 'Hercynian' (late Carboniferous–early Permian) at the time of the continent-to-continent collision of the Karakum plate and the central Kazakhstan-North Tien Shan continent (*Zonenshain et al., 1990*). The Hercynian compression led to the formation of north-dipping nappes. Two of these nappes transect the Tamdytau – a regional-scale syncline in the central part of the range and a regional-scale anticline in the south.

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[1] R.Kh. Mirkamalov, V.V. Chirikin, V.G. Kharin, R.S. Khan**.** On the age of granitoid and metamorphic complexes in the Tian-Shan fault belt (Uzbekistan)**.**Geologiya i mineral'nye resursy (1) (2012), pp. 5-14(in Russian)

[2] R.Kh. Mirkamalov, V.V. Chirikin, R.S. Khan, V.G. Kharin, S.A. Sergeev. Results of U-Pb (SHRIMP) datings of granitoid and metamorphic complexes of the Tien Shan folded belt (Uzbekistan) Vestnik St. Petersburg University, 7 (1) (2012), pp. 3-25(in Russian)

Additional evidence for this continent-to-continent collision in Uzbekistan includes the occurrence of fragments of oceanic crust (*Sabdyushev and Usmanov, 1971*). A refraction seismic survey (*Ivanov and Sabdyushev, 1974*) and two USSR Deep-Geodynamic Drilling Program holes located near the center of the Tamdytau confirmed the synclinal structure in the central and northern parts of the range (Sabdyushev and Voronov, 1990). Subsequent Hercynian transpression caused movement along the west-northwest-striking, left-lateral Sangruntau-Tamdytau shear zone and subsequently along the newly formed southwest-striking, left-lateral Muruntau-Daugyztau shear zone. The interplay of movements along these shear zones changed the strike of the eastern nose of the antiformal nappe, which resulted in a Z-like-shaped fold near the southeastern tip of the Tamdytau that is best observed in the so-called Besapan-3 unit (bs_3).

The core of this Z-fold is transected by brittle faults of the Muruntau-Daugyztau shear zone and it is within this area that the current Muruntau open pit mine was developed. Carboniferous–Permian granitoid intrusions were emplaced into the nappes, into the regional shear zones and transecting the inferred suture zone. The intrusion of the granitoids was controlled by deep-seated, basement-penetrating faults. The numerous intrusions shown directly to the west of the Tamdytau indicate that a zone of dilatancy must have existed in the regional synclinorium, presumably created by the same tectonic forces that formed the Z-shaped structure.

National Geologic history, stratigraphy and tectonics

There are three structural tiers on the geological map: **lower - Caledonian, middle - Varian, and upper - neotectonic.**

The lower structural stage (D-S2) is developed on the Tamdyn anticlinorium area and consists of volcanogenic - sedimentary, terrigenous and carbonate rocks of the Paleozoic. The zone of the foothill Tamdyn synclinorium also belongs to the time of its formation. The upper structural layer (Q) is a cover of Quaternary deposits of the foothill plain, lying on the leveled buried surface of Paleozoic formations. The main folded structure of the Paleozoic complex within the Foothill-tamdyn synclinorium is represented by the Tamdyn synclinal zone. The zone is characterized by steep wing drops and the development of numerous additional synclinal folds in the core, which were formed due to sinking along longitudinal faults.
Paleozoic (Pz)

Devon CD system

The deposits are represented by carbonate formations of the lower (Di), middle and upper carbonate - terrigenous divisions of the Devonian, characterized by rhythmicity.

The lower Devonian formations are distributed in the mountains and are represented by limestones with a basal horizon of gravelites and tuffs of Liparite composition. Their

capacity ranges from 100 - 150 m. The middle Devonian deposits belong to the stage and are distributed in the mountains where they are divided into four formations with a total thickness of 1400 - 1500 m: lower and upper.

Upper Devonian formations are mainly Frankivsk in the developed tier and in the mountains of Tamditau. Their capacity is about 1,000 meters. They are represented by limestones with layers of Dolomites, and at the top of the section siltstones and flints. In the mountains tamdytau are also Famennian limestones.

Regional geology: tectonic analyses

The regional geology of the Tamdytau area hosting the Muruntau gold deposit has been described in numerous publications. Only a brief overview is given in this section with focus on the tectonic evolution.

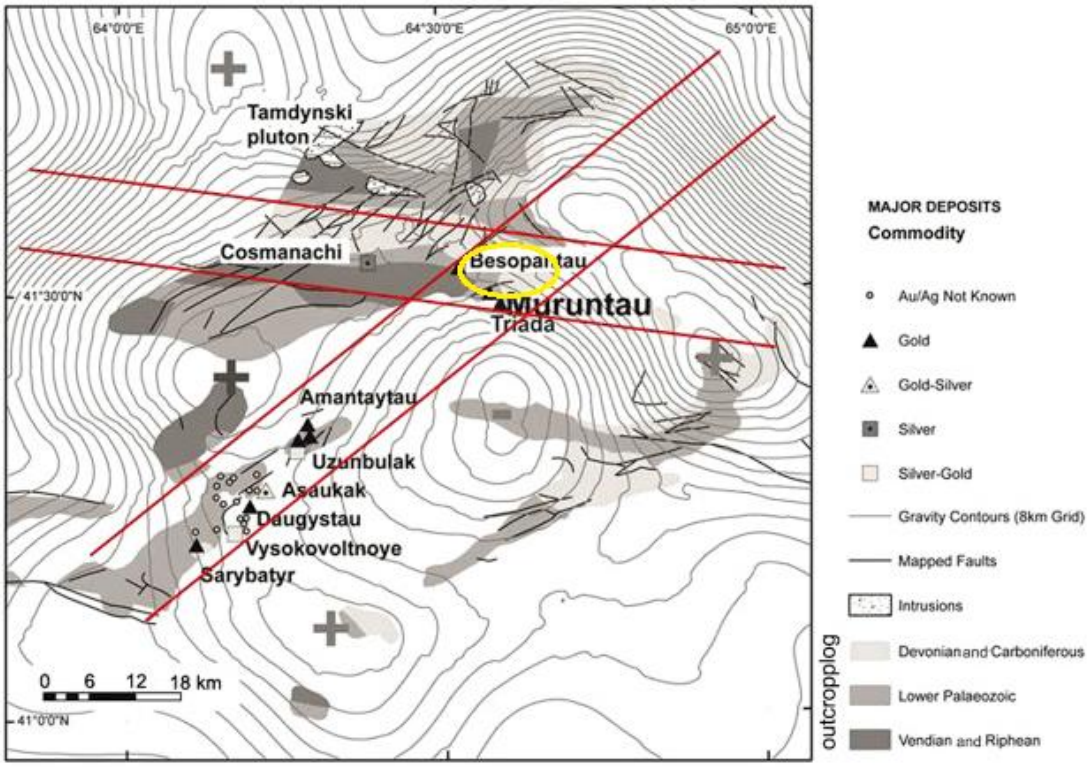

Figure 4. Position of gold and silver deposits in the Central Kyzylkum area aligning along the general northeast structural trend. Gravity contour grid (centres of negative anomalies and positive anomalies indicated by symbols) has been draped over the geological sketch map (modified from Bierlein and Wilde, 2010). Targeted area is located at the junction of two main structural zones (in red), the northeast structural trend supposedly representing a trans-crustal shear zone and a subhorizontal structural trend reflecting the E–W strike of thrusted stratigraphy and fold axes.

The deposit occurs within a pile of imbricated thrusts that was deformed into W–E-trending synforms and antiforms exposed in the Tamdytau (Tamdy Mountains) at the westernmost end of the southern Tien Shan. This structure consists of tectonically superimposed lithologies, which represent an early–middle Paleozoic oceanic to

accretionary and fore-arc complex rocks thrust onto Vendian–middle Paleozoic passive margin sedimentary rocks whose Vendian–lower Paleozoic part was metamorphosed in the amphibolite to green schist facies. The Muruntau-Daugyztau shear zone, along which there has been ductile and brittle deformation, is located in the southeastern portion of the Tamdytau. This fault strikes northeast-southwest and has been mapped over a length of 75 km and a width of about 5 km. Parallel faults were mapped to the northwest of the main fault zone in the same nappe and further to the northwest in the overlying synformal thrust package of Devonian and Carboniferous carbonate rocks.

The movements on the Muruntau-Daugyztau faults are left lateral, as may be seen from the movement of the fault-bounded slices of Devonian carbonate rocks located to the northeast of the Muruntau open pit. The evolution in tectonic stress from the thrusting to the strike-slip regimes is demonstrated by the imposition of steeply dipping left-lateral faulting on the previously developed nappes. Intense hydrothermal alteration occurs in areas within and adjacent to the Muruntau-Daugyztau shear-zone. The orientation of the swarm of fault segments of this shear-zone system in the Muruntau area is parallel to the axis of the nappe south of the Tamdytau, which suggests that they have been developed along axial fractures and (or) thrust faults formed during the 'Hercynian' continent-to-continent collision (Drew et al., 1996).

Besides the large nappe structures, Proterozoic and Paleozoic formations in the Tamdytau show several generations of deformation that record a history of transition from ductile to brittle deformation styles (Drew et al., 1996). Alekseyev and colleagues identified several distinct deformation events in rocks in the Amantaitau region southwest of Muruntau, the oldest of which consists of small- and large-amplitude isoclinal folds overturned to the east and north that fold the original bedding. Facing determinations indicate that some of the folds, which are about 2 km wide, were transformed subsequently into a series of tectonic slices (Alekseyev, 1979).

According to Drew et al. (1996), this isoclinal folding was followed by metamorphic recrystallization and, in turn, by more-open folding without significant metamorphism. Several subsequent kink-fold events preceded the final shear-zone deformation described above. Because of the direction of isoclinal folding and the transposition of schistosity fabric by the 'Hercynian' compression, much of this deformation is interpreted to be 'Caledonian' (The term "Caledonian" is frequently used in the Russian language literature as synonym for 'early Paleozoic' orogenic events that could have taken place along the margins of the northern continents or along the northern margins of Gondwana. These deformation events, including the tectonic slicing, are of great importance for structural controls on veining and the stratabound nature of some of the ore bodies in the Muruntau and adjacent Myutenbai deposits. Yakubchuk et al. (2002) suggested – based on their structural analysis of the regional and detailed maps

by Kotov and Poritskaya (1991) and by Drew (1993)– that there are two stratigraphically or tectonically controlled levels of highly silicified rocks in the Vendian-lower Paleozoic unit. The upper silicification level, which hosts Muruntau and all small satellite deposits in the area, e.g., Kosmanachi, Besopan, Myutenbai, Triada, etc., forms a more than 7 km-long lens-shaped unit matching with the east-west tending Tamdytau-Sangruntau shear zone. The silicification developed along structures of the regional Dzhanbulak antiform and the Muruntau deposit occurs exactly at the eastern closure of this antiform whose pattern suggests that there were several superimposed deformational events (D1–D4; Fig. 5a–d). In particular, the density of the D3 fold axes is much greater at the eastern closure of the antiform where the Muruntau deposit occurs and where Drew et al. (1996) recorded the Z-shaped folds and their offset by the youngest strike-slip faults (D4). This structural framework was a path-way for entrapment of fluids (Yakubchuk et al., 2002.

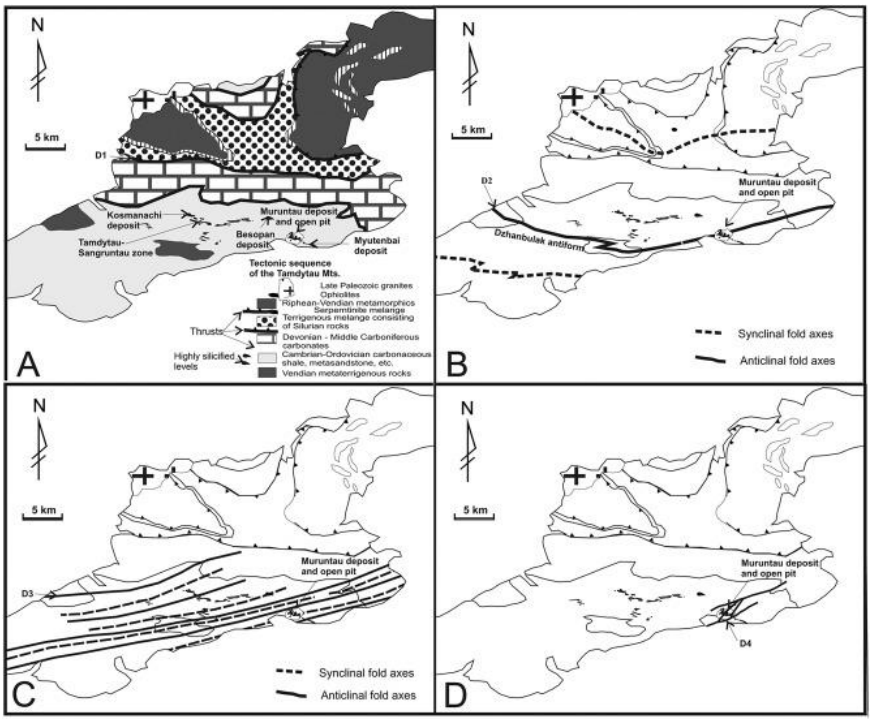

Figure 5. Structural scheme of the Tamdy mountains. The structure consists of a series of D1 imbricated thrusts (A) with Paleozoic rocks constituting the nappes occurring between the Precambrian rocks both in the base and in the uppermost allochthons. The latter is accompanied by serpentinite melange. This structure was deformed into WE-trending folds during the D2 event (B) and into NE-trending folds during the D3 events (C). Note that the Muruntau deposit occurs in the hinge of the Dzhanbulak antiform, an apparently best place for entrapment of fluids.

These late Paleozoic multiple episodes are responsible for tighter spacing of D3 folds at the closure of the Dzhanbulak antiform, location of fluids, and possibly granitoid intrusions. This structure was strike-slip faulted during D4 tectonic event (D), which supposedly took place in the Mesozoic.

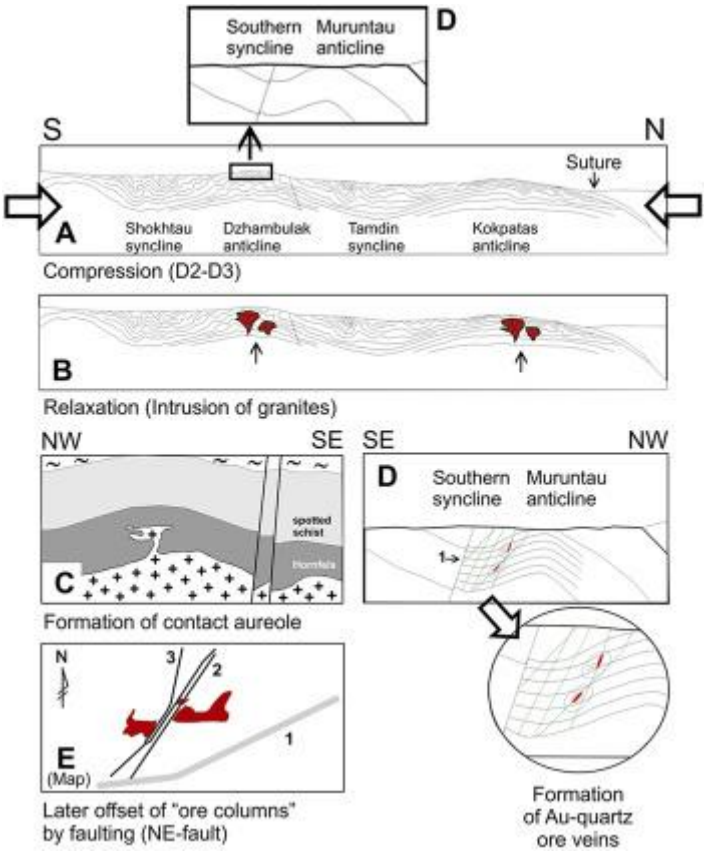

Figure 6. Model for the formation of the ore-bearing structures at Muruntau in relation to the structural evolution of the area and the major alteration phases present (Seltmann et al., 2003). Map E: 1 – Southern fault zone; 2 – Northeastern fault zone; 3 – Meridionalnyi fault.

Report from Tamdy municipiality

The picture described the splitting the land (no color photo). Based municipality report the land has been splitting in Tamdy region (1996). And experts reported that this zone (Tamdy region) is seismically dangerous zone and available faults (pic1).

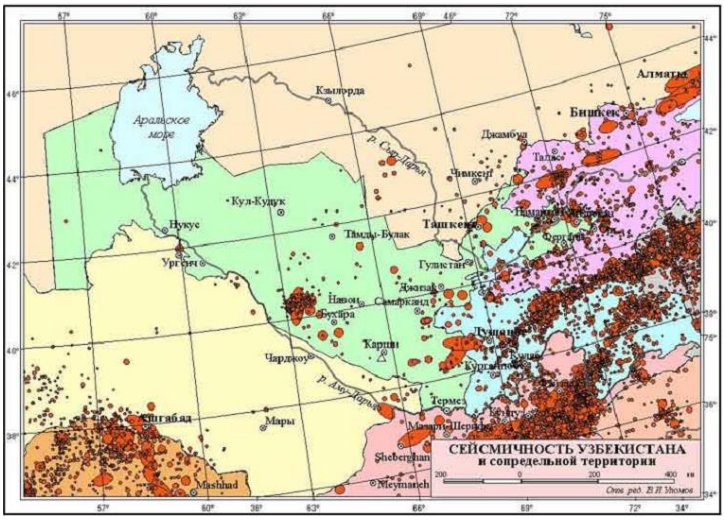

Figure 7. seismicity of Uzbekistan

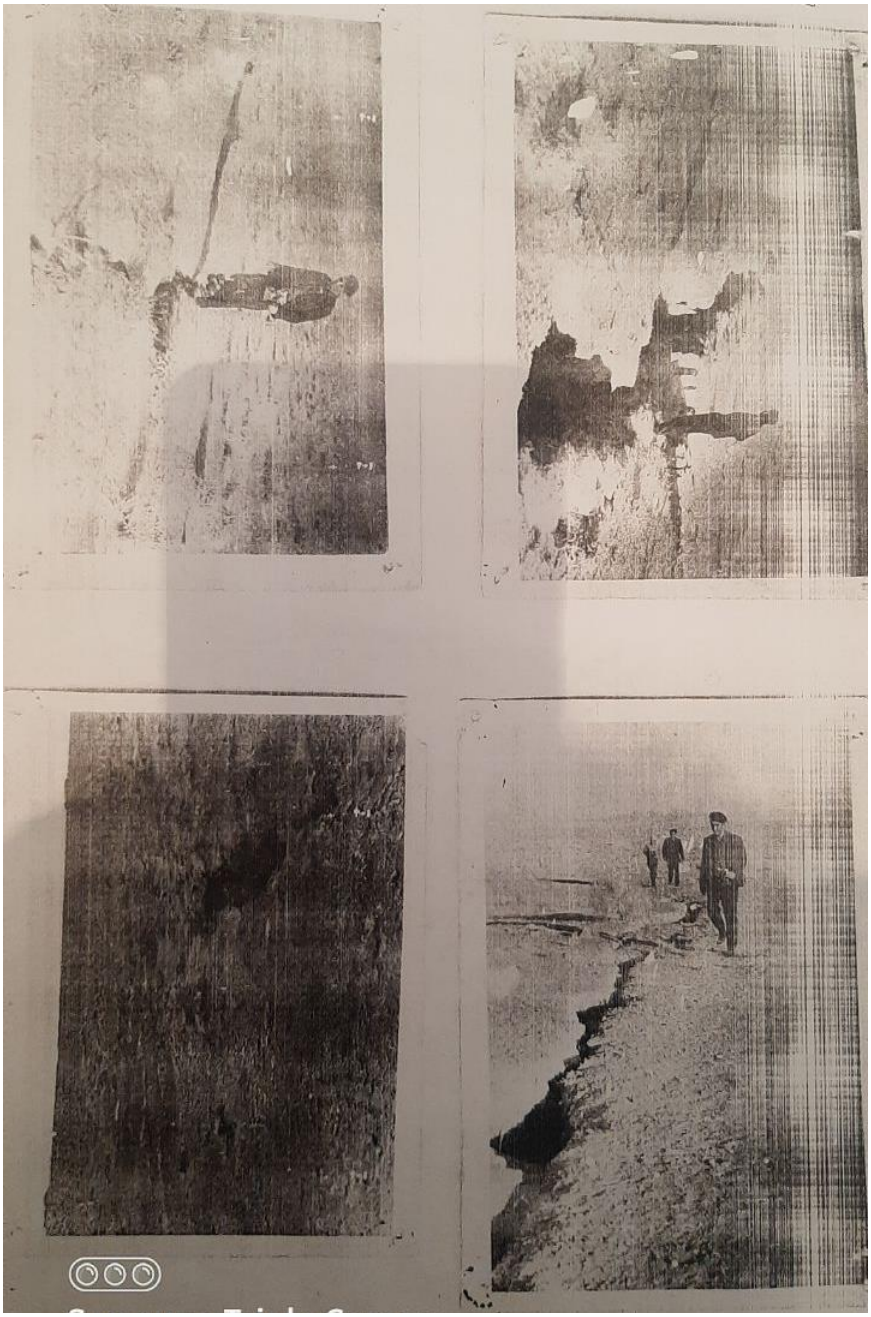

Photo 1. Fault processes in Tamdy area. Photo credit: Mr.Fazlullo Agzamov (recieved 08.10.2020)

Based on Seismology Institute, the map described "fault systems" in Uzbekistan, as targeted in the circle (blue line) it is area where it has been targeted for analyzing. II- means Bukantau and black dots observed faults. In the below just described II – Bukantau and their characteristics.

Based on findings of author Ulomov[3], 1974 the territory of Uzbekistan occupies the central part of Central Asia and is located in the area of transition from the mountain structures of the Tien Shan to the Turan platform. This transitional area is characterized

[3] Ulomov V.I. Dynamics of the Earth's crust in Central Asia and earthquake forecast.Monography. Tashkent: FAN. 1974. Pp-218 (In Russian)

by heterogeneous manifestations of seismicity due to the complex geodynamic interaction of lithospheric plates.

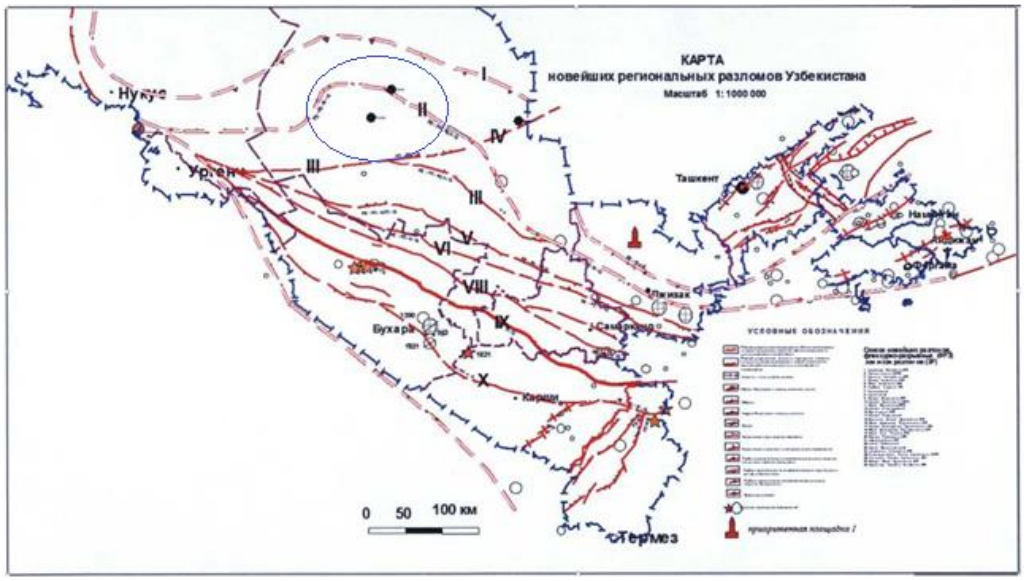

Figure 8. Schematic map based on faults in Eastern side of Uzbekistan on standard: UZB.0120.0.0.ES.DC0002

Fault systems: I – **North Kyzylkumskaya**; **II - Bukantau**; III – Besapano-South Ferghana; IV – Northern Tamdy; V – South-Auminzatau; VI - Northern-Kuljuktau-Zarafshan; VII – South-Turkestan; VIII - Southern-Kuljuktau-Zarafshan; IX – South Tianshan; X - Bukhara-Hissarian-Kokshal.

Credited: http://seismos-u.ifz.ru/personal/centrasia.htm

Bukantau fault system

The fault in plan repeats the structural pattern of the North Kyzylkum fault. In the sublatitudinal direction, it crosses the Bukantau and Tubabergen mountains further, bending smoothly in the north-western direction, continues to Sultanuizdag, where it merges into a single bundle with the rest of the region's fault systems. In the east, the fault runs along the southern margin of the positive morphostructures of Dzhetimtau and Toktyniktau, then acquiring a northwestern orientation, appears on the day surface in the Darvaztau region. To the southeast, it merges with the Northern-Besopano-Nurata fault. In a magnetic field, the fault is characterized by the junction zone of two sharply different sections of the field. In the gravitational field, it is fixed by a zone of high horizontal gradient (up to 35 ° E), as well as by the boundary along which there is a sharp change in the nature of the field and the sign of anomalies. Within Bukantau, the Paleozoic basement is divided by a fault zone into three blocks: northern, central, and southern. The central block has undergone the greatest fragmentation.

The northern block is uplifted relative to the southern one by 100 m. In this area, the fault zone is 4 km wide. To the east (Dzhetymtau mountains), the direction of fall of the mixer changes from north to south. The fault was initiated in the Early Paleozoic [10]. In the geosynclinal stage of development of the region, it actively developed, being the border of two different structural subzones. During the Mesozoic and Paleogene, the fault zone did not appear. In the Late Pliocene-Quaternary time, the fault became

active again. The amplitude of displacement for this period along the fault is estimated at 400 m.

Terrain description

The selected region is Tamdy. Tamdy is located northern side of Uzbekistan and administrative zone of Navoi region. Tamdynsky (Tamdy) district occupies the north-eastern and partly central part of the Navoi region. From the north and east it borders on Kazakhstan, in the west - with Uchkuduk, in the south-west - with Kanimekh, in the south-east across Lake Aydarkul - with Nurata district of Navoi region, in the extreme southeast - with Jizzakh region. The area of the district is 42.4 thousand km^2, and with this indicator Tamdynsky district is in second place in terms of area among the districts of the Navoi region (in the first place is the Uchkuduk district with an area of 46.6 thousand km^2). Almost the entire part of the region's territory is covered by deserts and steppes. The central part of the Kyzylkum desert is located in this district area (Tamdy). The formation of the land calcerous and low hills available randomly and highest hill height reached 300m a.s.l.

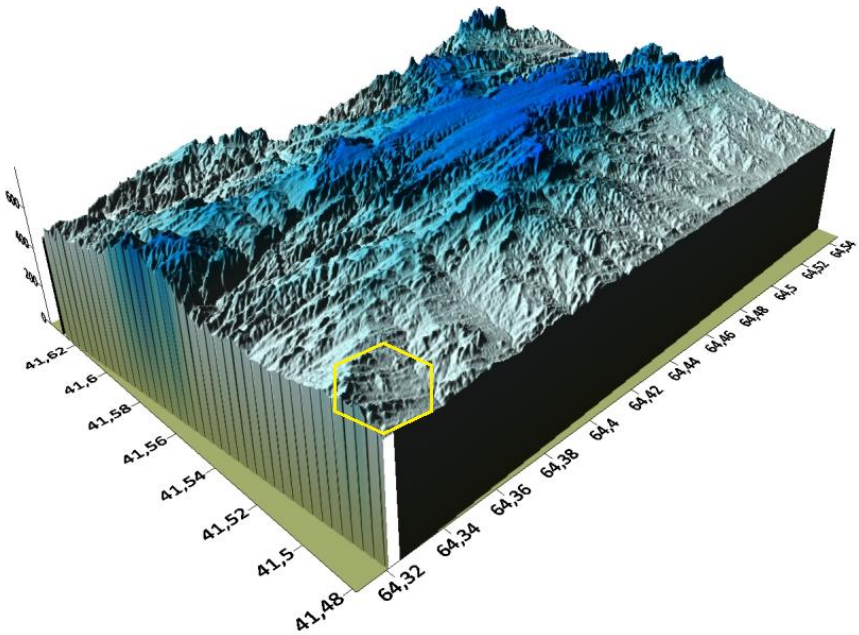

Figure 9. Terrain description in 3D model

Mineral resources

No data.

Soil cover around the project site / region

Soil classification is provided in .mdb file formats and are available to use under software HWSD. The mapping of topsoil (fig.8) for Navoi region showed that a vast area classified as specific features of general lithological–edaphic conditions in the formation of *deserts* and divided into six groups: sandy, sandy–gravel and gravel, crushed stone–gypsum, loess, clay, and solonchak. Due to deserts (a vast area occupied by deserts likely Kyzylkum, Karakum, and newest Aralkum) mostly area classified as sandy dunes (**DS**). Soil group for Tamdy zone is Sand dunes+Calcisol.

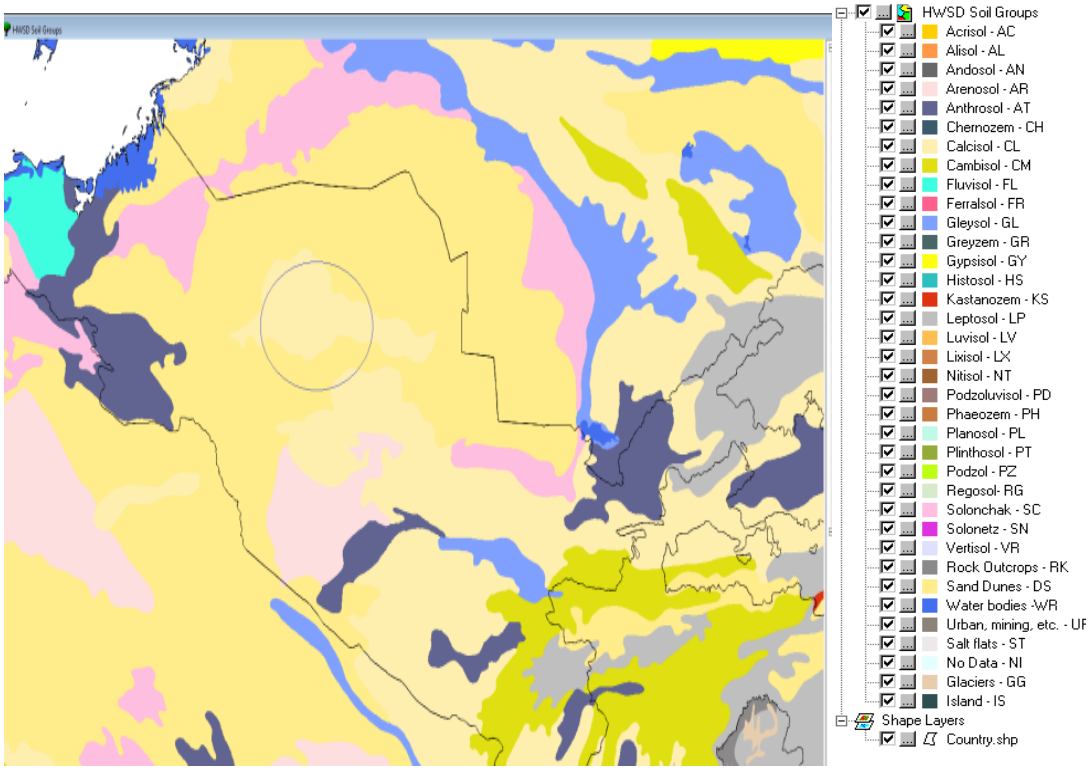

Figure 10. Soil top classification porosity derived from the Harmonized World Soil Database; lakes and sea are extracted, but water bodies are available

Soil erosion risks / any degradation

In Uzbekistan, land degradation occurs mostly as secondary salinization, rangeland degradation and desertification, as well as soil erosion. Negative environmental impacts due to land degradation include the drying up of the Aral Sea, water and air

pollution caused by salinization and erosion, which result in the loss of biodiversity and reduction of land ecosystem services[4].

Rainfall erositivity

Rainfall erosivity dataset (2017) is one of the input layers when calculating the Revised Universal Soil Loss Equation (RUSLE) model, which is the most frequently used model for soil erosion risk estimation; for the whole World; R-factor map at resolutions of 30 arc-sec ((~1 km at the Equator). Based on observation the area is not occurred on the rainfall erosivity (Tamdy region) and intensity of rainfall less observed in the region compare to the Fergana valley.

Wind erosion

No information.

Mudflow

More than 90 % of all recorded mudflows were associated with extreme precipitation events, hail and sleet, whereas 6 % of mudflow episodes were observed during intensive snowmelt events induced by respective temperature and precipitation changes (Chub et al., 2007). Glaciers melting due to increasing temperatures and mountain lake outbursts (Petrov et al., 2017) and dam failures has been suggested as a possible trigger of further minor mudflows (1.4 %) in the study area. Approximately 80 % of all recorded mudflow episodes with different origins occurred during the period of April–June. In the selected region the precipitation is not highest than 110-150mm/per year. And the low risk to update about mudflow occurrence.

Salinization

In the selected area the groundwater (GW) appears less due to aquifer depletion. The soil salinization might be increased from Aral Sea disappearance and salt crusts movement from bottom Aral Sea.

[4] In Book: Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development. Edited by Ephraim Nkonya, Alisher Mirzabaev, Joachim von Braun

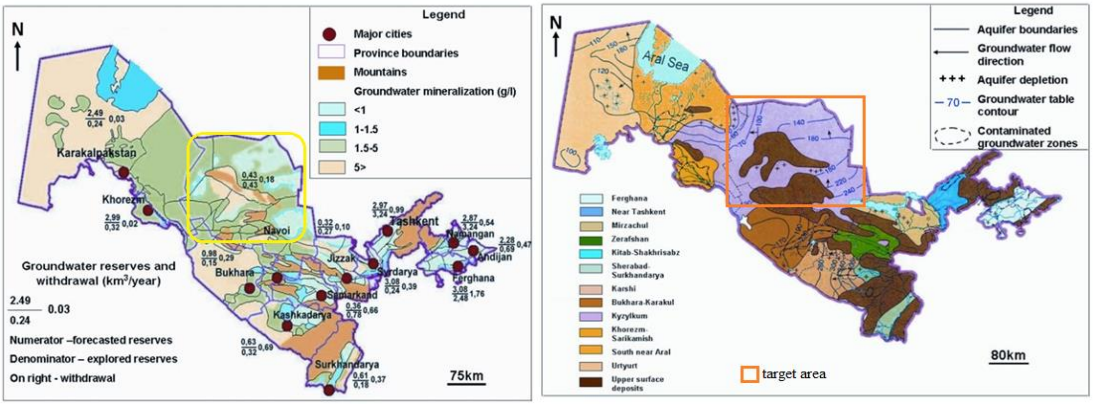

Figure 11. GW analysis for salinization level estimation

Dust

The duration of the shtil in the region is 16% per annum[5]. On average, sand and dust storms occur 20 days a year, mostly in summertime. Due to a high evapotranspiration, sand dunes lifted in the top of the air. Soil erosion is active in such conditions when the average daily temperature amplitude is 8.7^{0}C in January and 23.7^{0}C in July, with a maximum temperature of 46^{0}C and an absolute minimum of -26C in wintertime.

Seismic conditions

Uzbekistan norms and regulations on seismic zones. Location of the site against seismic code; context of the Global Seismic Hazard Assessment Project (GSHAP), a seismic hazard distribution map of Uzbekistan; please provide relevant maps of the area.There are three main tectonic domains (here described from N to S): (1) Northernmost (as part of middle Tien Shan), the Beltau-Kurama tectonic zone with recycled crust of continental arc (lower Carboniferous to mid-Permian, C1–P2), represented by the giant Kalmakyr Cu-Au porphyry (315 Ma, Seltmann et al., 2014[6]) emplaced within massive Devonian to Carboniferous sediments and volcano-plutonic units. To the west, the North-Bukantau tectonic zone is located which is characterised by lower Devonian to late Carboniferous (middle Carboniferous according to former Soviet stratigraphy; D_1–C_2) oceanic arc tholeiites with slivers of Cambrian oceanic crust and early to late Carboniferous (or middle Carboniferous according to the alternative system; C_1–C_2) bimodal volcano-plutonic arc rocks with volcanomictic carbonate-terrigenic series.

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[5] 16% of the year is approximately 58 days – these storms are usually occur in April and May months

[6] Seltmann et al., 2014

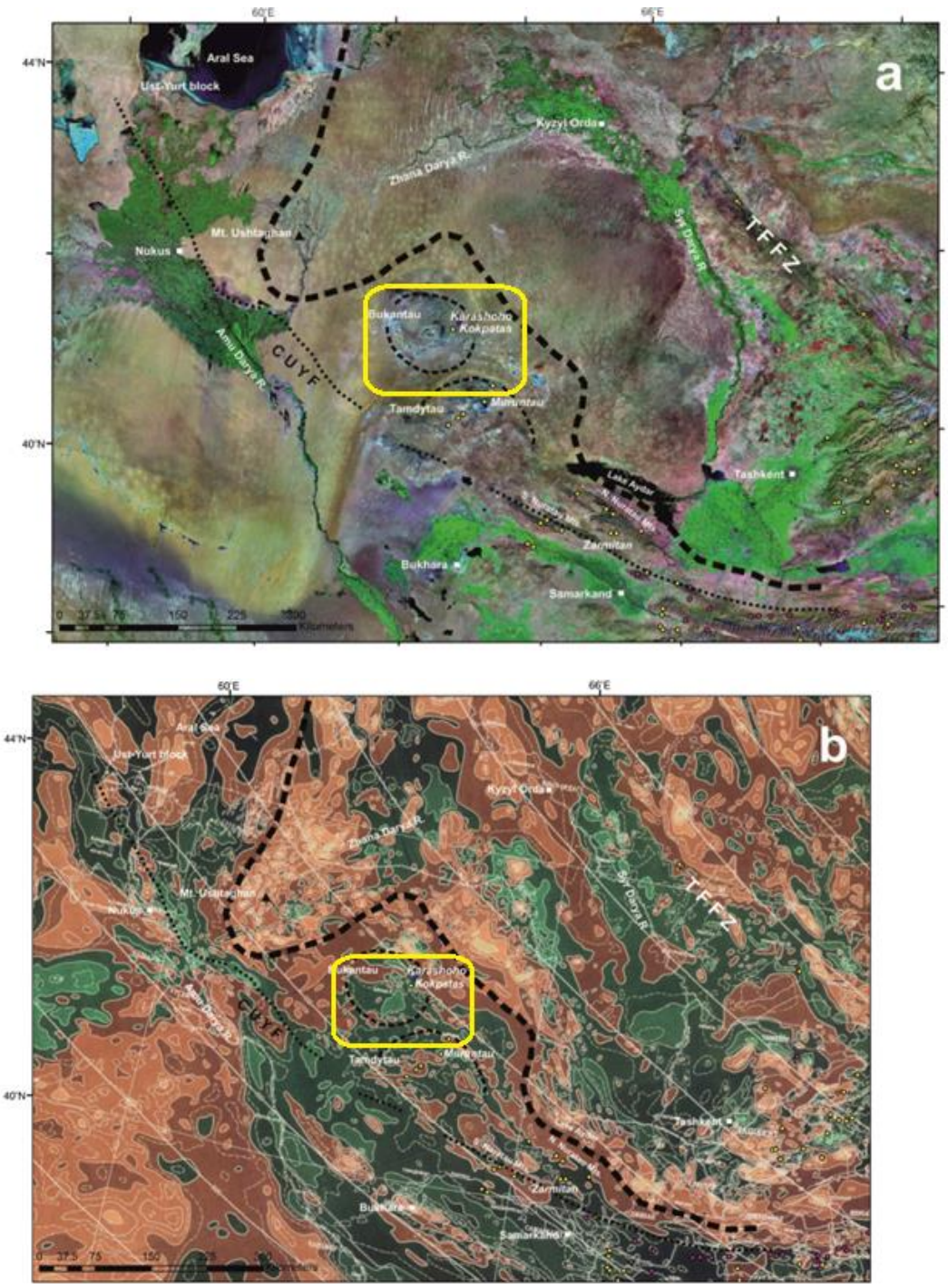

Figure 5(a) Overview of the Kyzylkum region with the divisions inferred from the magnetic anomaly map in (b).

Credited: https://www.sciencedirect.com/science/article/pii/S1674987115001139

The medium dashed lines of the Muruntau and Kokpatas anomalies, derived in (fig12b), find support in the morphology of the surface features. The anomaly expresses the Valerianov – Beltau-Kurama volcanic arc and the suture of the Turkestan Ocean. TFFZ – Talas-Fergana Fault Zone. The finely dotted line represents the Central Ust Yurt Fault (CUYF) whose trace is probably located along the southern margin of the South

Nuratau range (fig12b). The medium dashed lines represent the annular outlines of the Muruntau and Kokpatas anomalies. Yellow dots represent gold deposits and purple dots represent mercury and mercury-antimony deposits. The Karashoho lamproite near Kokpatas is diamondiferous.

Magnetic anomaly pattern of the Kyzylkum region between the Amu Darya and Syr Darya Rivers with interpretation of the major structures, also showing ore deposits, towns and rivers. Positive anomalies are in brown to white colour pattern, and negative anomalies are in dark to light blue colour pattern. Heavy dashed line separates the high-frequency eastern part of the main Kyzylkum anomaly from the lower-frequency western part of the anomaly.The imagery provides further indication of complex configurations in the subsurface, which at the regional scale reside in:

1. A split in the west-north westerly structural Tien Shan grain north of Samarkand, with one branch continuing along strike and expressed by the ranges along the Central Ust Yurt Fault towards Nukus and a second branch diverging from the southern Nuratau Mountains to a more northwesterly direction towards the Tamdytau and Bukantau areas (Fig. 12a).
2. The continuation of the latter structural grain into a semi-circular westward trend with east-west diameter of some 80 km particularly defined by the contacts between the Mesozoic and Cenozoic sediments with the crystalline complex of Tamdytau (Fig. 12a).
3. Further northwest, the crystalline complex of the Bukantau hills is surrounded by a ring of younger sediments, with a diameter of about 100 km (Fig. 12a).

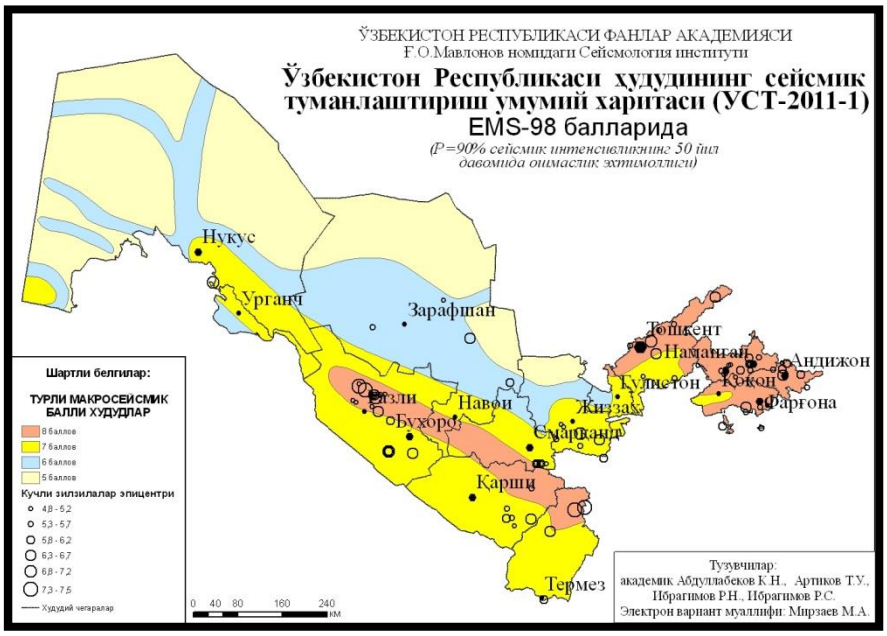

Figure 13. **Microseismic ratings (balls) in the regions of Uzbekistan**

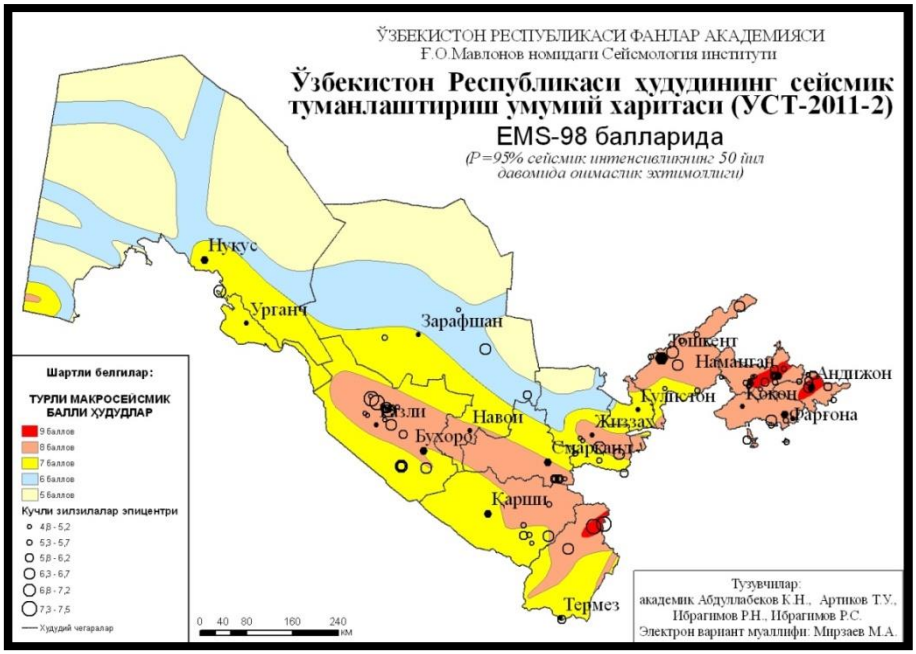

Figure 14 Seismic regionalization of the Republic Uzbekistan (yellow 5 ball, dark yellow 7, and blue 6ball)

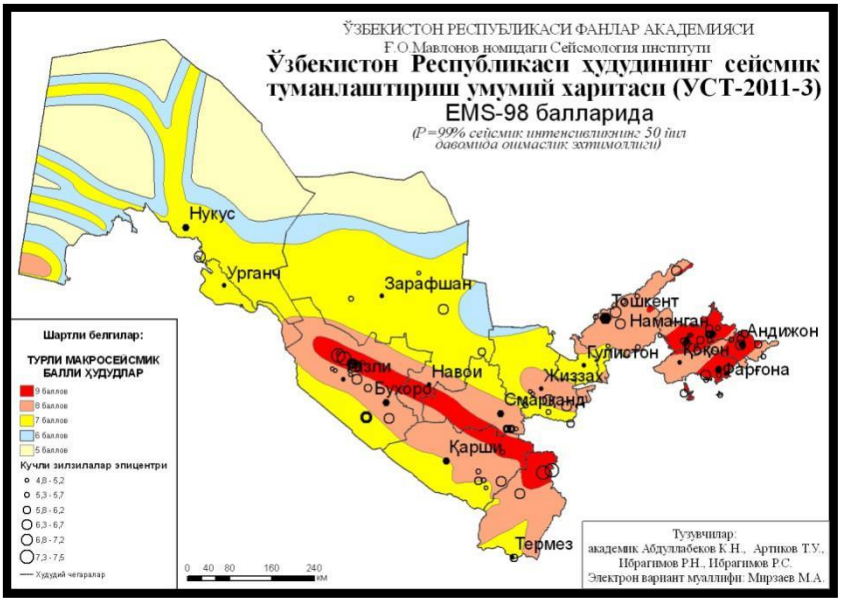

Figure 15. Seismic regionalization of the Republic Uzbekistan (yellow 5 ball, dark yellow 7, and blue 6ball). Epicentric earthquakes observed in Navoi region from 6.8-7.2 and 4.8-5.2)

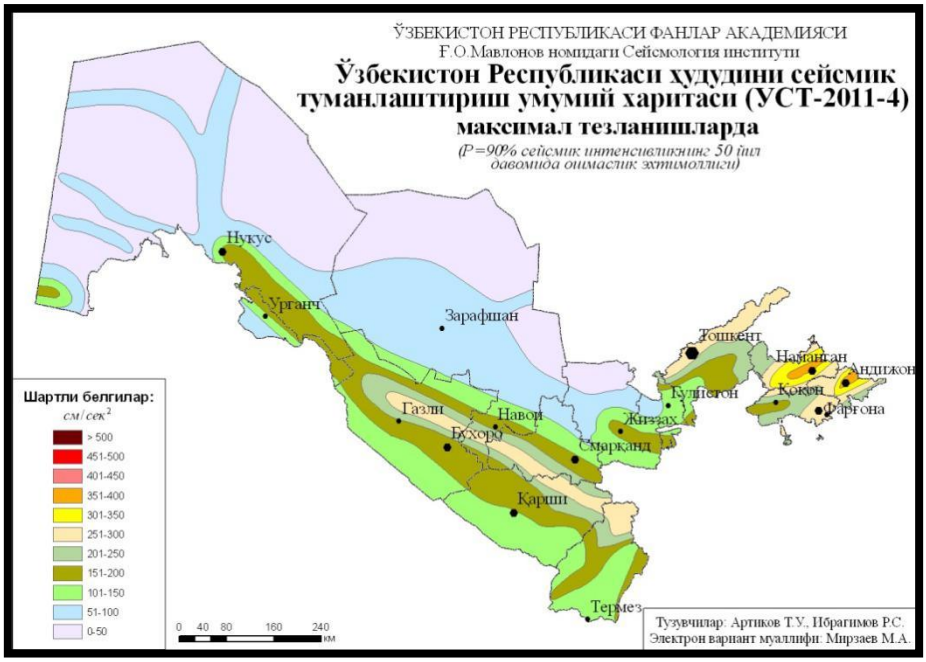

Figure 16 General map of Seismic regionalization with maximal speedity (sm/second^2)

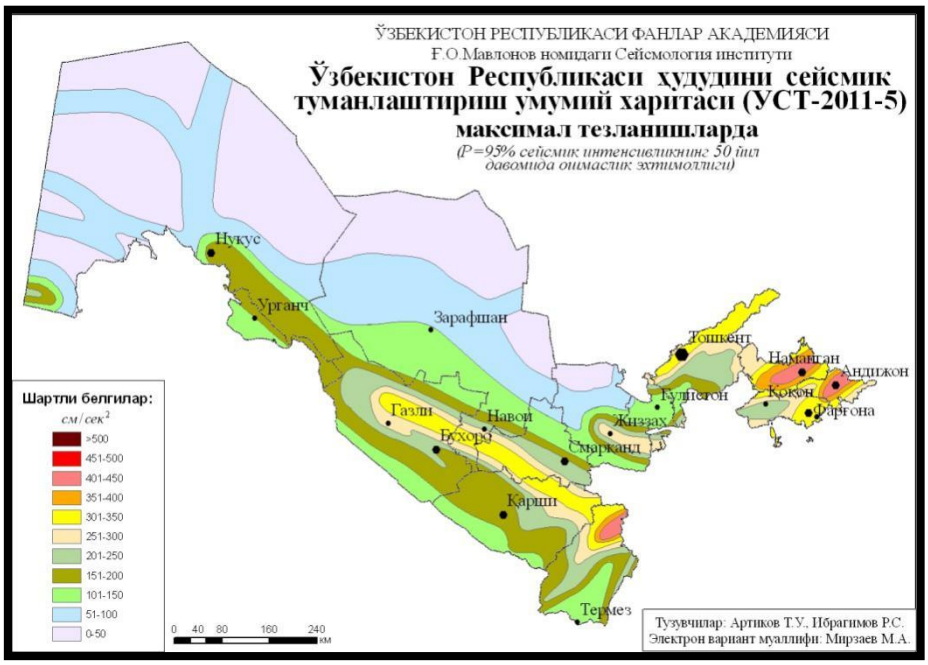

Figure 17 General map of Seismic regionalization with maximal speedity (sm/second^2)

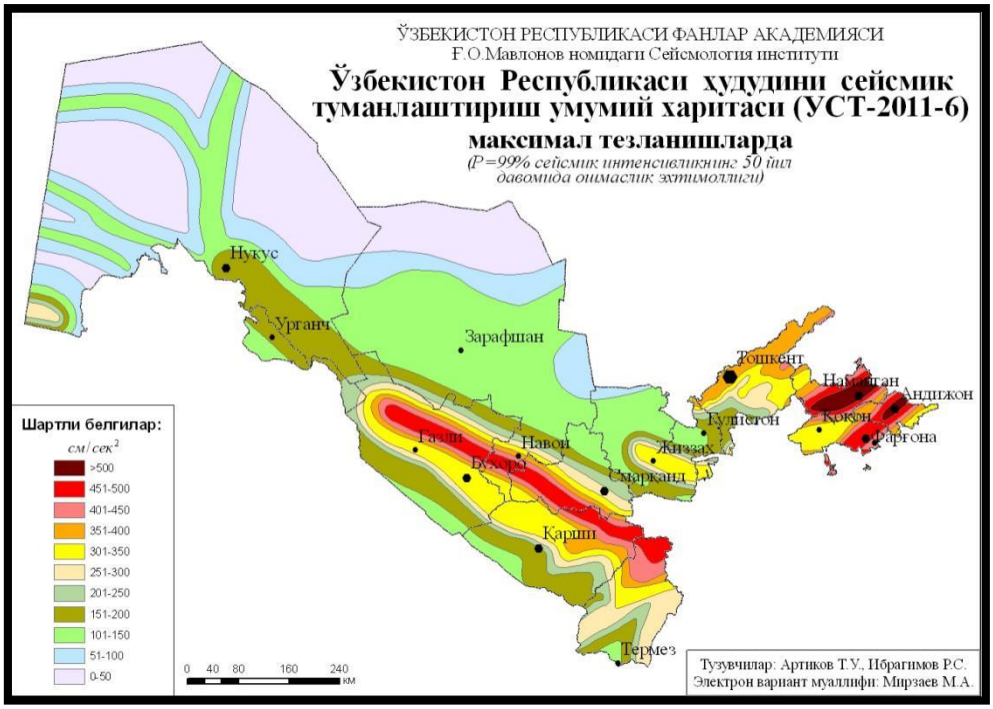

Figure 18 General map of Seismic regionalization with maximal speedity (sm/second^2)

Additional references:

Kempe Ulf, Graupner Torsten, Seltmann Reimar, Hugo de Boorder, Alla Dolgopolova, Maarten Zeylmans van Emmichoven.The Muruntau gold deposit (Uzbekistan) – A unique ancient hydrothermal system in the southern Tien Shan. Geoscience Frontiers. Volume 7, Issue 3, 2016. Pages 495-528,ISSN 1674-9871, https://doi.org/10.1016/j.gsf.2015.09.005

http://seismos-u.ifz.ru/personal/pdf/Ulomov_dynamics_crust_1974%20(OCR).pdf

Additional maps credited from following web sites:

http://seismos-u.ifz.ru/personal/centrasia.htm